

Human Factors Engineering for Space Exploration Missions

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Abstract

NASA now has a focused mission for space exploration. We will continue to use ground based analogs and simulators, the Space Shuttle and the International Space Station as research and development platforms, but the challenges of time, distance and very hostile environments raise the challenges to human factors engineering designers to an even greater level. We will have a new generation of vehicles, equipment, habitats and space suits; operations and activity management will present novel scheduling, training and task allocation opportunities. The safety stakes will also be higher and the cold euphemisms of risk management will require some humanization, both for the crew and the public.

Space vehicle launch, docking, navigation and landing will require complex interactions between automation and human operators. Commanders and pilots will require considerable simulator training and will be expected to perform flawlessly despite the debilitating exposure to extended time in space. Physical tasks on planetary surfaces will require protective suits that allow explorers to function effectively without the risk of excessive fatigue. Deviations from our familiar 24 hour day night cycle will demand innovative countermeasures if crew members are not to succumb to performance decrements due to cumulative sleep deprivation. Operation of complex life support, transportation, emergency response and scientific systems will require the development of effective and efficient job aids and procedures. Planetary surface habitats will be designed with the life support systems and home comforts necessary for long duration tenure. Finally, the safety of the human crew will be paramount and will require robust hybrid human-robotic systems, activity schedules and operations management.

The NASA space human factors community is addressing these challenges by observing the performance of crew members in analogs, simulators and real missions and supporting this activity by basic and applied research in NASA laboratories and in

collaboration with external scientists. The presentations in this panel will describe some of the current efforts to support this focused NASA exploration mission.

Introduction

NASA now has a focused mission for space exploration. We will continue to use ground based analogs and simulators, the Space Shuttle and the International Space Station as research and development platforms, but the challenges of time, distance and very hostile environments raise the challenges to human factors engineering designers to an even greater level. We will have a new generation of vehicles, equipment, habitats and space suits; Operations and activity management will present novel scheduling, training and task allocation opportunities. The safety stakes will also be higher and the cold euphemisms of risk management will require some humanization, both for the crew and the public.

Performance in the Spacecraft Cockpit – Jeffrey McCandless Ph. D, San Jose University, NASA ARC

Space vehicle launch, docking, navigation and landing will require complex interactions between automation and human operators. Implementation of advanced technologies in the cockpit of a next-generation spacecraft will require a thorough understanding of human-computer interaction. In particular, developers need to understand how crewmembers and intelligent software agents can work together to perform fault detection, isolation and recovery (FDIR). The level of automation during FDIR needs to be appropriate for different conditions that may occur in spaceflight. These challenges are being investigated in a number of settings, including the Intelligent Spacecraft Interface Systems (ISIS) Lab. The ISIS Lab is a fully reconfigurable simulator with liquid crystal display (LCD) screens representing cockpit displays, and touch-screens representing physical switches. Because of this design, the display and switch information can be changed to represent

different configurations. In addition, the ISIS Lab contains a head-mounted eye-tracker for monitoring eye-position. Performance results obtained with former United Airlines pilots in the ISIS Lab have provided insight into issues relevant for next-generation spacecraft design.

Anthropometry and Biomechanics of Planetary Surface Suits - Sudhakar Rajulu Ph. D, NASA JSC / NSBRI

Physical tasks on planetary surfaces will require protective suits that allow explorers to function effectively without the risk of excessive fatigue. The constraint is that the crewmember must also be provided with air to breathe and be protected from the harsh environment that may have zero (air) pressure, microgravity, extremes of light, large thermal loads (both hot and cold), micrometeorites, dust and radiation. These constraints usually require a multi layered pressurized suit with strategically placed joints, carried life support systems and appropriate information and communication systems. The crewmembers may also be expected to carry tools and materials and may perform their duties in collaboration with automated aids, such as a robotic arm or surface vehicle. The result of these constraints is that the current suits greatly restrict functional physical activity which results in tasks taking much longer than they would do on earth with an unencumbered operator. The problem may be further compounded by physical debilitation following an extended journey in microgravity. The challenges are being addressed by innovative systems designs that include sensory and motor augmentation and intelligent robotic assistants for the EVA astronaut. The basic anthropometric and biomechanical challenges of fit and function become even more important in these challenging contexts. These challenges are being met by contemporary measurement and predictive modeling approaches.

Sleep in Space Melissa Mallis Ph. D. NASA, ARC

Deviations from our familiar 24 hour day night cycle will demand innovative countermeasures if crew members are not to succumb to performance decrements due to cumulative sleep deprivation. Sleep/wake cycles of astronauts during space operations have been documented to deviate from the 24-hr day due to a variety of scheduling and environmental factors. Consequently, sleep times and waking alertness can be compromised. There is considerable evidence that sleep is chronically reduced during space operations compared to 8hr sleep on the ground. These reductions are often at a level below which waking performance can be reliably sustained (i.e., < 6.5hr sleep per night). Such decrements often times can be difficult to detect and counter effectively in restrictive operational environments. Therefore, NASA and the National Space Biomedical Research Institute (NSBRI) are currently funding research in the development of optimal sleep/wake schedules and countermeasure timing/application to help mitigate the cumulative effects of sleep loss and enhance operational performance. It should be noted that a "day" on the International Space Station lasts about 90 minutes, at the moon pole about 14 days and on Mars the day is about 24.6 hours. Thus the challenge of managing sleep will become greater as we move further away into space.

Procedures for Space Operations, Mihriban Whitmore, Ph. D. NASA JSC

The small number of people that comprise a crew in a space mission must carry with them a great deal of knowledge and many skills that are supplemented by automation, just in time training, procedures or other job aids. The problem is further compounded by the large amount of general and special training needed for a space mission that must be carried out over a number of years before the mission starts. Operation of complex life support and scientific systems will require the development of an effective combination of these intelligent agents that is designed to meet both routine and emergency situations. As missions move further away from

earth and communication lags become greater, the crewmembers will have to rely totally on their memories or the procedures that accompany particular tasks, rather than be guided by more experienced information resources on earth. Procedure design presents a particular challenge. Where a crewmember has considerable related background and is very familiar and practiced at a task, lengthy procedures may be counterproductive; on the other hand tasks that are not carried out routinely or require meticulous adherence to process, must be guided by very precise procedures. An important case is that of emergency medical procedures. These may need to be found and followed over very short time periods, while the injured crew member and crew medical officer are managing the extra challenge of stabilization of themselves and their supplies in microgravity. These challenges are being addressed by the development of innovative just in time information systems that use the richness of graphic devices and augmented reality, to supplement the text and logic diagrams.

Space Habitats - Frances Mount, Ph. D. NASA JSC / NSBRI

Planetary surface habitats will be designed with the life support systems and home comforts necessary for long duration tenure. The limited volume on the Space Shuttle has been found to be tolerable for relatively short missions, but the longer duration International Space Station missions have already been hampered by the challenges of stowage and retrieval of equipment, tools and materials that are due to a large extent to the limitations of the load capacity of the transfer vehicles. Missions to the moon will also have limited resupply opportunity and missions to Mars will have to take everything they need, including air, water and food with them, send it on ahead of time, or make it / mine it / grow it and process it in situ. The second habitability challenge of space missions is due to the extremely unforgiving environments – microgravity, heat (cold), radiation, micrometeorites, dust and unwanted chemical and biological organisms. Failure or substandard performance of the monitoring and control systems will lead to both performance decrements and increased stress on the

crew. The third issue in habitability stems from the psychological and social dynamics that envelop small teams in stressful contexts, including communication, decision making, contextual leadership, relaxation and privacy.

These habitability and the associated human performance challenges are being addressed by the AIM (Advanced Integration Matrix) project, which aims to provide ground based testing capabilities in preparation for exploration missions to the Moon and Mars. This project focuses on integrated testing and searches for the predictable and unexpected interactions among the many mission subsystems including the human subsystem. The project will also serve as a dress rehearsal for space missions in which crew and support team members are trained for extended periods in self contained analog environments.

Safety in Space - Cynthia Null, Ph. D. NASA ARC

The safety of the human crew on exploration missions is paramount, despite the unforgiving context and engineering complexity; it will require robust multi-agent human-robotic systems and operational demands to perform like a well practiced orchestra. In many ways, space exploration is like many historical human explorations – crossing oceans, climbing mountains, going to the poles, deserts, jungles or ocean beds. The first risk is the unforgiving context, the second is the complexity and the third is uncertainty. NASA is addressing some of the more thorny safety challenges by the formation of the NASA Engineering and Safety Center:

“.....the NESC is one of several initiatives involved in returning the Shuttle to safe flight, its broader objectives include strengthening and expanding the agency's safety, mission assurance, and engineering disciplines for all NASA programs. The NESC is a "One NASA" effort that will involve all NASA facilities in meeting these objectives.

Meeting these objectives will require the best and brightest engineers, scientists, researchers, and technicians to become part of the NESC team.”

“Planned activities of the new organization include:

- Independent engineering assessment and testing to support critical NASA projects and programs
- Engineering and safety review and evaluation through independent analysis, hazard and risk assessment, safety audit, and participation in mishap investigations
- A central location for independent trend analysis utilizing state-of-the-art tools and techniques
- A structure to support engineering collaboration for problem resolution
- Central coordination of engineering and programmatic lessons learned, technical standards, and technical discipline expertise
- Independent inspection and validation of activities to ensure the constant maintenance of NASA safety standards”

The Human Factors contribution to this effort is through the formation of a panel of experts, from academia, industry and within NASA to carry out in depth assessment and make recommendations for risk mitigation.

Conclusions

The NASA space human factors community is addressing the challenges of exploration missions to the Moon, Mars and beyond by observing the performance of crew members in earth analogs (in the desert, at the poles and under the sea), simulators and real (International Space Station) missions and supporting this activity by basic and applied research in NASA laboratories and in collaboration with external scientists. The presentations in this panel will describe some of the current efforts to support this focused NASA exploration mission. Following the panel presentations the audience will be encouraged to discuss opportunities for transfer of knowledge and human factors approaches from other contexts to the unique space exploration domain.

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